WAAS for Telecom Sync Applications

...part of the Satellite-Based Augmentation Systems (SBAS) programs

http://GPS.FAA.GOV/Programs/WAAS/waas.htm

Hugo Fruehauf
hxf@fei-zyfer.com
February 2007
Rev 2-7-07
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
Definitions

Ground-based Differential GPS Augmentation System designed to meet the needs of world’s Civil Aviation Navigation Community:

- **WAAS** - Wide Area Augmentation System (USA & territories, Canada, Mexico)
- **EGNOS** - European Geostationary Navigation Overlay System (Europe, Africa, Venezuela)
- **MSAS** - Multifunctional Transport Satellite Space-Based Augmentation System (Japan, Australia, Hawaii)
- **GAGAN** - GPS-Aided Geo Augmented Navigation (India, China, and other Asian territories)
Why has it taken 20 years to use GPS for Civil Aviation?

• With SPS, accuracies are not good enough to meet FAA’s Category I, II, and III requirements
  - Needs Differential Corrections (DGPS) and elimination of SA (in case SA is activated)
  - Needs improved Vertical Accuracy through use of added Range Signals from overhead satellites
  - Needs improved Ionospheric Corrections

• With SPS, Signal Reliability is not good enough; Can be out of limits without real-time user knowledge
  - Needs to be forward looking enough to allow a safe abort
  - Receiver Autonomous Integrity Monitoring (RAIM) addresses the “Reliability/Integrity” need
## FAA Requirements vs. GPS Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GPS C/A  (Spec)</th>
<th>GPS C/A  (Typ.)</th>
<th>GPS P(Y)  (Spec)</th>
<th>GPS P(Y)  (Typ.)</th>
<th>FAA Requirements CAT I</th>
<th>FAA Requirements CAT II</th>
<th>FAA Requirements CAT III</th>
<th>WAAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Position Accuracy (2σ)</td>
<td>100 m</td>
<td>10 m; 22 m</td>
<td>6 m, 1σ</td>
<td>2 m</td>
<td>16 m</td>
<td>6.9 m</td>
<td>6.1 m</td>
<td>7.6 m Typical 1 to 2 m</td>
</tr>
<tr>
<td>Vertical Position Accuracy (2σ)</td>
<td>156 m</td>
<td>15 m; 27.7 m</td>
<td>6 m, 1σ</td>
<td>3 m</td>
<td>7.7 m</td>
<td>2 m</td>
<td>2 m</td>
<td>7.6 m Typical 2 to 3 m</td>
</tr>
<tr>
<td>Time Accuracy to UTC (2σ)</td>
<td>340 ns</td>
<td>35 ns</td>
<td>200 ns</td>
<td>20 ns</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>25 ns Typical 5 ns</td>
</tr>
<tr>
<td>Decision Height (DH)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200 ft</td>
<td>100 ft</td>
<td>50 ft</td>
<td></td>
</tr>
</tbody>
</table>
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
Local Area Differential GPS Concept

GPS Sats

Exact Known Location

GPS Solution for DGPS Sta.

DGPS Ref. Sta.

Data Link Transmitter

Position Correction transmitted to User

User Applies Correction to Range Measurements

Error

X

Y

Z
Contents

- Why WAAS?
- What is Differential GPS?
- **What is WAAS?**
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
Wide Area Augmentation System Concept

Wide Area Reference Stations:

- WAAS - 18 WRSs for USA Mainland, ~25 Total (13 more being added, ~38 Total)
- EGNOS - 44 WRSs for Europe, Africa, Venezuela
- MSAS - 6 WRSs for Japan, Australia, Hawaii
- GAGAN - 18 WRSs for India, China and other Asian areas

Wide Area Augmentation System Concept

Inmarsats, plus other (GeoSync Sats)

Transponded "bent-pipe" to L1 - C/A

C-Band Uplink, 6.4 GHz

C-Band C/A from Uplink Station

(2) Ground Uplink Stations

(2) Wide Area Master Stations

DGPS Data

L1-C/A "look-alike" 250 bps

Ionospheric Effects

L1-C/A 50 bps

GPS Sats

L1-C/A from GPS Sats

(21 to 30) GPSs
(½ GeoSync Orbits)

USNO

Time

GUS

Data-Link

USER

WRS

WRS

WRS

WMS

Frequency Electronics Inc.
The availability of service at the edge of coverage beams fluctuates depending upon a variety of conditions. The map depicts Inmarsat's expectations of coverage but does not represent a guarantee of service.

Limit of global beam coverage for Inmarsat A,B,C,D,E,M

- Pacific Ocean Region
- Atlantic Ocean Region-West
- Atlantic Ocean Region-East
- Indian Ocean Region

Satellites on-line for the SBAS/WAAS Infrastructure

The availability of service at the edge of coverage beams fluctuates depending upon a variety of conditions. The map depicts Inmarsat’s expectations of coverage but does not represent a guarantee of service.
Satellites on-line for the SBAS/WAAS Infrastructure

<table>
<thead>
<tr>
<th>SBAS</th>
<th>Satellite</th>
<th>Orbit Longitude</th>
<th>PRN No.</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGNOS</td>
<td>Inmarsat-3-F2/AOR-E</td>
<td>15.5° W</td>
<td>120</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Artemis</td>
<td>21.5° E</td>
<td>124</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Inmarsat-3-F5/IOR-W</td>
<td>25° E</td>
<td>126</td>
<td>A</td>
</tr>
<tr>
<td>MSAS</td>
<td>MTSAT-1R</td>
<td>140° E</td>
<td>129</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>MTSAT-2</td>
<td>145° E</td>
<td>137</td>
<td>C</td>
</tr>
<tr>
<td>WAAS</td>
<td>Inmarsat-3-F4 (AOR-W)</td>
<td>142° W</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inmarsat-3-F3/ POR</td>
<td>178° E</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intelsat Galaxy XV</td>
<td>133° W</td>
<td>135</td>
<td>D, F</td>
</tr>
<tr>
<td></td>
<td>TeleSat Anik F1R</td>
<td>107.3° W</td>
<td>138</td>
<td>E, F</td>
</tr>
</tbody>
</table>

C/A-codes (PRN No’s) – 120 to 138 are reserved for the SBAS/WAAS Infrastructure
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- **WAAS Signal Characteristics**
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
WAAS Downlink

- L1-C/A GPS 'Look-Alike' signal from each GEO-Satellite with no SA (same signal strength as GPS satellites)
- DGPS Vector Corrections for each GPS Satellite
- Added Pseudo-range Signals (available) via each GEO-Satellite
- Receiver Autonomous Integrity Monitor (RAIM) in Airborne WAAS receivers (a “Use/Don’t Use” flag)
- Improved Ionospheric Correction
- 250 bps data rate rather than the GPS 50 bps
  - Needed to transmit DGPS correction data for each GPS Sat
  - More frequent update - every 6 Sec. for DGPS and RAIM
  - Time to “Not-Use” Alarm 5.2 seconds
## WAAS Message Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Contents Summary</th>
<th>Spec Sect. #</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Don’t use for Safety applications</td>
<td>4.4.1</td>
</tr>
<tr>
<td>1</td>
<td>PRN Mask assignments, set up to 51 of 210 bits</td>
<td>4.4.2</td>
</tr>
<tr>
<td>2-5</td>
<td>Fast corrections</td>
<td>4.4.3</td>
</tr>
<tr>
<td>6</td>
<td>Integrity information</td>
<td>4.4.4</td>
</tr>
<tr>
<td>7</td>
<td>Fast Correction Degradation Factor</td>
<td>4.4.5</td>
</tr>
<tr>
<td>8</td>
<td>Estimated RMS Error message</td>
<td>4.4.6</td>
</tr>
<tr>
<td>9</td>
<td>GEO navigation message (X, Y, Z, time, etc.)</td>
<td>4.4.11</td>
</tr>
<tr>
<td>10</td>
<td>Degradation Parameters</td>
<td>4.4.16</td>
</tr>
<tr>
<td>11</td>
<td>Reserved for future messages</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>WAAS Network Time/UTC offset parameters</td>
<td>4.4.15</td>
</tr>
<tr>
<td>13-16</td>
<td>Reserved for future messages</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>GEO almanacs message</td>
<td>4.4.12</td>
</tr>
<tr>
<td>18</td>
<td>Ionospheric grid point masks</td>
<td>4.4.9</td>
</tr>
<tr>
<td>19-23</td>
<td>Reserved for future messages</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>Mixed fast corrections/long term satellite error corrections</td>
<td>4.4.8</td>
</tr>
<tr>
<td>25</td>
<td>Long term satellite error corrections</td>
<td>4.4.7</td>
</tr>
<tr>
<td>26</td>
<td>Ionospheric delay corrections</td>
<td>4.4.10</td>
</tr>
<tr>
<td>27</td>
<td>Reserved (Service Level Message)</td>
<td>-</td>
</tr>
<tr>
<td>28</td>
<td>Clock-Ephemeris Covariance Matrix</td>
<td>4.4.17</td>
</tr>
<tr>
<td>29-61</td>
<td>Reserved for future messages</td>
<td>-</td>
</tr>
<tr>
<td>62</td>
<td>Reserved (Internal Test Message)</td>
<td>4.4.14</td>
</tr>
<tr>
<td>63</td>
<td>Null Message</td>
<td>4.4.13</td>
</tr>
</tbody>
</table>
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- **What’s New for Telecom?**
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
**What’s New for Timing/Sync?**

- **WAAS/EGNOS/MSAS/SNAS capability** is designed for high-end airborne GPS Receivers for Civil Aviation Navigation ($5K to 10K?) - No thoughts given to other users

- **New** - Making the typical low cost, ($100 or so) small GPS Timing Receiver capable to receive and process **WAAS-only signals** (both DGPS corrections as well as ranging with WAAS)

- **Advantages:**

  For **Timing Users**, partial backup to GPS L1-C/A in case of GPS C/A signal loss (done through use of the “Don’t Use” WAAS Warning Flag)

  For **Timing Users**, more resistant to unintentional or intentional jamming/noise environments (done through use of a dish antenna)

  For **Timing Users**, a more accurate position solution (done though better Multipath Mitigation and Ionospheric Corrections)
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
    - Jamming Resistance (Dish Antenna)
    - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status


**WAAS backup to GPS C/A signals for the Timing Community**

When GPS Navigation Solution is unusable in a number of SBAS areas (in **How Many?** No one knows at present)

---

**Frequency Electronics Inc.**

---

**WMS**

Cesium Stds/WRS + Data-Link

---

**USNO**

Timing from Cs Stds

(C/A Look-alike created here from Cs Clocks, not GPS Sats)

---

**USNO**

Timing Timing

---

**Std. GPS Ant. or 18” Dish pointed to GeoSync Sat**

---

**Telecom Terminal**

---

**Transponder**

InmarSats, plus other (GeoSync Sats)

---

**C-Band C/A from Uplink Station**

---

**“bent-pipe”**

---

**“Don’t Use” Flag**

---

**GPS Sats**

---

**GPS Generated L1-C/A, 50 bps**

---

**InmarSat-generated L1-C/A “Look-alike” 250 bps**

---

**C-Band Uplink**

---

**InmarSats, plus other (GeoSync Sats)**

---

**WRR**

---

**C-Band C/A from Uplink Station**

---

**Timing from Cs Stds**

---

**USNO Timing**

---

**C-Band Uplink**

---

**WMS**

---

**Timing from Cs Stds**

---

**USNO Timing**

---

**C-Band C/A from Uplink Station**

---

**WRS**

---

**Cesium Stds/WRS + Data-Link**

---

**USNO**

Timing from Cs Stds

(C/A Look-alike created here from Cs Clocks, not GPS Sats)
"WAAS-only capable" GPS/WAAS Rcvr Performance

<table>
<thead>
<tr>
<th>Sat Visibility and Rcvr Configuration</th>
<th>With Std GPS Antenna Stability Performance</th>
<th>With Dish Antenna Stability Performance</th>
<th>Test Plot No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std. (12) Channels GPS Sats in view, + WAAS Sat; position averaging</td>
<td>&lt; 50 ns P-P (&lt; 20 ns RMS) *</td>
<td>&lt; 20 ns P-P (&lt; 10 ns RMS)</td>
<td>1 **</td>
</tr>
<tr>
<td>(3) Channels GPS Sats in view, + WAAS Sat; 40° mask angle; fixed position</td>
<td>&lt; 50 ns P-P (&lt; 20 ns RMS) * (unchanged)</td>
<td>&lt; 20 ns P-P (&lt; 10 ns RMS) (unchanged)</td>
<td>2 **</td>
</tr>
<tr>
<td>(1) Channel GPS Sat in view, + WAAS Sat; 40° mask angle; fixed position</td>
<td>&lt; 150 ns P-P (&lt; 50 ns RMS) *</td>
<td>&lt; 20 ns P-P (&lt; 10 ns RMS) (unchanged)</td>
<td>3 **</td>
</tr>
<tr>
<td>WAAS Sat only, (no GPS Sats); fixed position</td>
<td>&lt; 20 ns P-P (10 ns RMS) ***</td>
<td>&lt; 12 ns P-P (~5 to 6 ns RMS) ***</td>
<td>4 **</td>
</tr>
</tbody>
</table>
Plot 1 - Time Accuracy, Std Ant.

- Std. (12) Channels GPS Sats in view, + WAAS Sat; position averaging

50 ns
(3) Channels GPS Sats in view, + WAAS Sat; 40° mask angle; fixed position

50 ns
Plot 3 - Time Accuracy, Std Ant.

(1) Channel GPS Sat in view, + WAAS Sat; 40° mask angle; fixed position

50 ns
Plot 4 - Time Accuracy, Std Ant.

WAAS Sat only, (no GPS Sats); fixed position

50 ns
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
Using a Dish for GPS and WAAS Reception

- More jamming resistant,
~10 to 15 dB gain from 18” Dish
18” TV Satellite Dish Test for WAAS

The goal for the test was to determine:
• Obtain signal gain through the use of a parabolic dish
• Determine if enough GPS Sats are visible for a position solution

Set-up
• Modify 18 inch Satellite TV dish (DBS) by removing its receiver
• Replace receiver with a standard GPS antenna at the focal point
• With indicated signal strength of the receiver, estimate the gain
• Manually focus antenna on WAAS satellite AOR-W (SV# 122)

Results
• Signal increased from ~ 35 dB to ~47 dB, an approx. 12 dB additional gain (w/o reversing signal polarization)
• Receiver tracked up to 8 GPS satellites at the same time
• No problem or additional delay in the initial acquisition was noted
• No noticeable change in signal strength of the GPS satellites that were being tracked
Modified 18 inch commercial TV Sat. Dish

Replace DBS Receiver at focal point with GPS Antenna
Tracking (1) WAAS and (7) GPS Satellites with an 18 inch modified commercial TV Sat. Dish
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
**Multipath Signal Mitigation and better Ionospheric Corrections**

- For GPS, multipath-caused delays are ever changing, because GPS satellites are in motion. This changes signal direction and consequently a reflection change from the surrounding objects.

- Contrary to GPS, the WAAS satellites are stationary. Therefore, with std. GPS antenna, the WAAS signal will see a “standing” (constant) multipath.
  - This will appear as an UTC time offset of ~30 to 40 nanoseconds with a Std. GPS Antenna
  - With a Dish Antenna pointed to a WAAS satellite, it rejects stray signals from entering dish aperture. In the same way, the dish also reduces the GPS-generated multipath signals.

- WAAS signal provides (dish or no dish) near real-time Ionospheric delay resolution through the use of the WAAS DGPS ground stations.
  - The corrections are updated every ~3 hours and transmitted as part of the WAAS signal 250 bit data stream.
  - This compares to the GPS signal 50 bit data stream, which transmits an Ionospheric correction model, infrequently. **Will be resolved in the future with L2-C/A**
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
# GPS Signals vs. WAAS Signals Availability

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Navigation Users</th>
<th>T/F Users</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal GPS Service Under Standard Conditions</strong></td>
<td><strong>GPS SPS (CIVIL)</strong></td>
<td><strong>WAAS Signals (EGNOS, MSAS, GAGAN)</strong></td>
</tr>
<tr>
<td></td>
<td>C/A, No SA (Navigation Solution &lt;10 m, Time Error &lt;100 ns)</td>
<td>C/A w/o SA, (even if SA is On, WAAS Filters it Out; (Nav Solution &lt;3 m typical)</td>
</tr>
<tr>
<td></td>
<td><strong>GPS PPS (MIL)</strong></td>
<td><strong>At Telecom Terminal (for T/F Sync)</strong></td>
</tr>
<tr>
<td></td>
<td>P(Y) (Good P(Y) PVT Solution)</td>
<td><strong>GPS + WAAS C/A w/o SA + Corrections</strong></td>
</tr>
<tr>
<td><strong>C/A becomes unavailable in a Local Area (due to friendly or hostile Jamming)</strong></td>
<td>No GPS C/A (SPS goes down in local area)</td>
<td>Terminal in local area goes on “Holdover” Clocks</td>
</tr>
<tr>
<td></td>
<td>Normal PPS P(Y) Continues</td>
<td>(Civil Navigation goes down in local area)</td>
</tr>
<tr>
<td></td>
<td>(Need Direct P(Y) Acq. Receiver for Cold-Start in Local Area)</td>
<td>(If Dish Ant. is used, it may defeat the Jammer !!)</td>
</tr>
</tbody>
</table>

Frequency Electronics Inc. WAAS not setup to detect local signal reception problems
### GPS Signals vs. WAAS Signals Availability

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Navigation Users</th>
<th>T/F Users</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Satellite SA is turned on and cranked High</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/A with sever SA (Navigation Solution 1000 m?? Time Error &gt;1 us ??)</td>
<td>C/A with sever SA (Navigation Solution 1000 m?? Time Error &gt;1 us ??)</td>
<td>C/A w/o SA from GeoSats, but WAAS may be out of Spec (Most SA is filtered by WAAS)</td>
</tr>
<tr>
<td>Normal PPS P(Y) Continues; Increased SA does not materially affect P(Y)</td>
<td>Normal PPS P(Y) Continues; Increased SA does not materially affect P(Y)</td>
<td>Terminal filters SA, WAAS C/A is w/o SA, Time should stay in 100ns area</td>
</tr>
<tr>
<td><strong>C/A is Unavailable from Satellite, (unthinkable scenario, but possible)</strong></td>
<td>No GPS C/A (SPS Goes Down Worldwide)</td>
<td>WAAS - GUS generated C/A will maintain Timing/Sync - GUS Clocks referenced to USNO(1) (50ns)</td>
</tr>
<tr>
<td>Normal PPS P(Y) Continues (Need Direct P(Y) Acquisition Receivers for Cold-Start)</td>
<td>Normal PPS P(Y) Continues (Need Direct P(Y) Acquisition Receivers for Cold-Start)</td>
<td>WAAS - GUS generated C/A will maintain Timing/Sync - GUS Clocks referenced to USNO(1) (50ns)</td>
</tr>
<tr>
<td>GPS/WAAS Civil Aviation Navigation goes down Worldwide. (WAAS - GUS generated C/A transmits “Don’t Use” message)</td>
<td>GPS/WAAS Civil Aviation Navigation goes down Worldwide. (WAAS - GUS generated C/A transmits “Don’t Use” message)</td>
<td>WAAS - GUS generated C/A will maintain Timing/Sync - GUS Clocks referenced to USNO(1) (50ns)</td>
</tr>
</tbody>
</table>

Note (1): With no GPS Satellite-generated C/A, all civil navigation is down. No need to shut down WAAS, EGNOS, MSAS & GAGAN; signals cannot be used for navigation, but ok for Timing/Sync.
Contents

- Why WAAS?
- What is Differential GPS?
- What is WAAS?
- WAAS Signal Characteristics
- What’s New for Telecom?
  - GPS Back-up
  - Jamming Resistance (Dish Antenna)
  - Better Positioning
- GPS/WAAS Operational Scenarios
- WAAS Infrastructure Status
**Future of WAAS**

- **MSAS**
  - ~6 Stations
  - Japan
  - Australia
  - Hawaii
  - Initial Testing
  - Since 1999
  - IOC 2007

- **EGNOS**
  - ~44 Stations
  - Europe
  - Africa
  - Venezuela
  - Initial Testing
  - Since 2000
  - IOC 2007

- **WAAS** – IOC was July 2003, presently (4) GeoSats (a FAA Project)
- **EGNOS** in test with (3) GeoSats (an EU, ESA Project)
- **MSAS** in test with (2) GeoSats (a Japanese Space Agency Project)
- **GAGAN** in start-up stage (an India/China – Aviation Cooperation Program (ACP), controlled by the Indian Space Research Agency (ISRO))
- **Interoperability between all Systems expected 2009?**